Vol. XI, Sec. A, No. 5 September, 1916

THE PHILIPPINE JOURNAL OF SCIENCE

ALVIN J. COX, M. A., Ph. D.
GENERAL EDITOR

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CHEMICAL AND GEOLOGICAL SCIENCES AND THE INDUSTRIES

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MANILA
BUREAU OF PRINTING
1916

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THE PHILIPPINE
JOURNAL OF SCIENCE
A. CHEMICAL AND GEOLOGICAL SCIENCES
AND THE INDUSTRIES

VOL. XI SEPTEMBER, 1916 No. 5

PHILIPPINE PAVING-BRICK MATERIALS: A PRELIMINARY REPORT[1]

By J. C. WITT

(From the Laboratory of General, Inorganic, and Physical Chemistry, Bureau of Science, Manila, P. I.)

ONE PLATE AND 1 TEXT FIGURE

INTRODUCTION

One of the needs of the Philippine Islands is a cheap and satisfactory paving material for streets and roads. There are a number of imported products which give good service, but the cost of transportation prohibited their extensive use even before the present increases in freight rates. Imported paving brick has always been out of the question for this reason, but asphalt has been used from time to time. However, at present, high freight rates prohibit the further importation of this substance, and the supply on hand in Manila is being used only on repair work. As a result, the city must now depend almost entirely on macadam, which is the only class of paving that can at present be made on an economic basis from Philippine raw materials. Macadam is satisfactory for some purposes, but is, of course, not well adapted to heavy traffic. Paving of concrete alone or of concrete mixed or surfaced with bituminous substance, is used in some cities in the United States with various degrees of success, but unfortunately cement is another material which is not available for streets to any great extent. There is one mill in the Philippine Islands manufacturing cement from local raw materials, but the present output is not adequate to supply the cement for building purposes alone.

The area of each kind of paving in use in Manila (December

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[1] Received for publication June 2, 1916.

31, 1915) and the approximate cost per square meter are given in Table I.

TABLE I.—*Various paving materials in use on Manila streets.*

Kind of paving.	Area.	Original cost per square meter.	Annual maintenance per square meter.
	Sq. m.	*Pesos.*[b]	*Pesos.*
Wood block	13,270	16.00	0.09
Stone block	35,370	not available.	very little.
Tar macadam	71,435	3.00	0.14
Macadam for—			
Heavy traffic	1,560,117	2.40	0.13
Medium traffic		2.00	
Light traffic		1.20	

[a] The information was obtained from the city engineer of Manila.

[b] One peso Philippine currency is equivalent to 50 cents United States currency.

Total length of improved streets and alleys, 192,446 meters.
Total paved area, 1,680,192 square meters.

The table shows that more than 92 per cent of all paving in Manila is macadam, and the percentage is increasing. The initial cost is low, but the high cost of maintenance prevents it from being an economical material.

ADVANTAGES OF PAVING BRICK

It is generally conceded that a vitrified-brick pavement will stand harder wear and give more satisfactory service for heavy traffic than any other except one of stone block. The cost of constructing a stone-block pavement is not excessive, and the maintenance is practically negligible for many years. However, such a pavement has a number of disadvantages. The edges of the blocks usually wear round, and a very rough street results. Such a pavement is hard on horses. Besides, it is noisy, and dirt settles in the cracks and cannot be removed by sweepers. The street is neither attractive nor sanitary when it is wet. In most large cities of the United States the stone-block pavement is confined to streets having only the heaviest traffic.

A brick pavement when properly constructed is very satisfactory. It wears smooth, offers little resistance to traction, and requires little maintenance.[2] Concerning the growth of the vitrified paving-brick industry in America, Blanchard and Drowne[3] say:

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[2] Although a number of unsatisfactory brick pavements may be found in the United States, the difficulty with each is usually easy to find. As a rule the fault lies in the bricks themselves, in the foundation, or in the filler. In some cases the fault is with the traffic. This may have originally been too heavy for a brick pavement or may have greatly increased after the pavement was laid.

> The first piece of brick pavement in the United States was a short experimental section laid in Charleston, West Virginia, in 1870. This was followed by another experimental piece laid in Bloomington, Illinois, in 1875, and a few other sections laid from time to time, up to 1885, in different cities of the Middle West. The use of this kind of pavement then began to increase rapidly, and at the present time there are very few large cities in the country that do not have some of their streets paved with this material. A census taken of the permanent pavements laid in 1910, in the United States, showed that brick was one of the most popular forms of pavement, considering the number of cities that have used it. From this census it was found that while sheet asphalt was first from the standpoint of yardage in the 460 cities reported, brick was a close second. It is natural that the greatest yardage should occur in those cities throughout the Central States since this locality abounds with clay deposits suitable for the manufacture of paving brick and is devoid of road building stone.

Evidently what is needed in the Philippines is the local manufacture of some paving material, because it is unlikely that shipping rates will ever be sufficiently low to allow the importation of large quantities. The Bureau of Science has long considered paving brick to be well adapted to local conditions, and the possibility that it may be made from Philippine raw materials has led to the present investigation.

DIFFICULTIES TO BE OVERCOME

It is not an easy task to find a raw material suitable in every respect for making paving brick in the Philippines. In the United States various geological surveys have been made, and if one desires to install a brick factory, he can easily obtain information concerning the various deposits of clays and shales and their working properties, location, and available fuels. The points to be considered in such an investigation for the Philippines are:

Raw materials.—A clay or shale must be selected with the necessary properties to produce vitrified paving brick, either alone, or mixed with some other material. In case two materials have to be used, they must be located near each other.

Transportation.—The raw material must be in an accessible place where brick machinery can be installed and transportation to Manila can be had. On account of the lack of wagon roads in many undeveloped parts of the Islands and the comparatively limited kilometers of railroad, it is likely that only some locality near water transportation could be considered.

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[3] Blanchard, A. H., and Drowne, H. B., Text Book on Highway Engineering. John Wiley and Sons, New York (1914), 550.

Fuel.—The high price of imported coal at present prohibits its use in burning brick. Therefore, if a factory is to be operated on an economical basis, it is desirable to locate it near a deposit of Philippine coal or other available fuel.

It would be very expensive to locate a large number of deposits and obtain samples for the investigation except in conjunction with other work. Thus far no systematic survey devoted exclusively to brick materials has been made. Most of the samples have been obtained at very little cost by members of the Bureau of Public Works and of the Bureau of Science who were in the field on other lines of duty. The Director of the former bureau has kindly sent a circular letter to all district engineers, requesting them to keep a lookout for shales and clays and to send samples of any promising material to the Bureau of Science.

RÉSUMÉ OF PREVIOUS WORK AT THE BUREAU OF SCIENCE

Systematic investigation of Philippine clays was started at the Bureau of Science by Cox.[4] According to the author, his object was—

> rather to show in a preliminary way the geological distribution and quality of clays on Luzon, than to pronounce on their economic value.

In the course of his work he examined more than thirty samples of clays, making chemical analyses and physical tests. Study of his paper clearly reveals the general character of the clays of Luzon. Some of the clays had already been used by Filipinos and Chinese in the manufacture of brick and pottery. The author says:

> The common clays of Luzon are already [1907] used in several places in the manufacture of brick and crude pottery. For example, the brick-kilns at Mandaloyon and the one near San Pedro Macati, on the Pasig River near Santa Ana, each of which employs from ten to twenty laborers, turn out from one to three thousand bricks a day per kiln. * * * No sand is added to it before molding, but the whole bank is broken down, mixed by the tread of carabaos, and used for the bricks. This makes the composition slightly different * * * but tests of the shrinkage and tensile strength show that its physical properties remain almost unchanged.

In his second paper[5] the same author says:

> This investigation was undertaken at the request of the Bureau of Education to enable it to choose a clay for use in the pottery school, the

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[4] Cox, Alvin J., *This Journal, Sec. A* (1907), 2, 413.

[5] Ibid., *Sec. A* (1908), 3, 377.

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building for which is now being erected in Santa Cruz. None of the clay deposits of Laguna Province have been thoroughly studied up to the present time and, therefore, I will first discuss those so situated that the stripping of the material would entail the least labor and the soil overlying could easily be disposed of. Such clays would be economical to use were they of high grade.

The work consisted in accurately locating a number of clay deposits and in examining their chemical and physical properties. It was found that—

> all of the high grade clays of Laguna Province are more or less mixed with clay of poorer quality. It is a question what percentage of the mixture is useful and whether the expense of sorting will not be so great that it can not compete with kaolin from other sources.

Adams and Pratt[6] give a report on the pottery industry in the Philippines up to 1910. This paper contains considerable information on the crude processes in use for making pottery, the general equipment, and other points of interest. The authors visited a number of potteries and brick factories.

> The usual type [of kiln] is a long semicylindrical structure built on a grade of about 10 per cent, having a chimney at the upper end and a door and hearth at the lower. There are also openings for firing along the sides of the kiln. They are constructed of volcanic tuff and common brick laid up and plastered over with mud. The fuel used is wood. A high temperature can not be obtained in these kilns and the semivitrified products from some of them are due to the low fusing point of the clays used. There is considerable shrinkage in burning, and when the clay fuses the sand used to prevent cracking comes to the surface, making the ware rough and pebbly.

A study of Philippine clays in relation to pottery manufacture has been made by Crowe,[7] of the Philippine School of Arts and Trades.

The papers mentioned above are the only ones published so far by the Bureau of Science in which the properties of Philippine clays are considered directly in connection with ceramics. However, papers have appeared on Portland cement raw materials[8] which deal with clays and shales.

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[6] Adams, G. I., and Pratt, W. E., *This Journal, Sec. A* (1910), 5, 143.

[7] Crowe, C. H., *Trans. Am. Cer. Soc.* (1912), 14, 723.

[8] Cox, Alvin J., Philippine raw cement materials, *This Journal, Sec. A* (1909), 4, 211.

Reibling, W. C., and Reyes, F. D., The efficiency of Portland cement raw materials at Naga, Cebu, ibid. (1914), 9, 127.

Pratt, W. E., Geological and field relations of Portland cement raw materials at Naga, Cebu, ibid. (1914), 9, 151.

PRESENT STATUS OF BRICK MAKING IN THE PHILIPPINES

Brick manufactured at a number of places in the Islands[9] is intended for building purposes only, and much of it is of inferior quality. Two of the factories visited may be briefly described here.

The factory near San Pedro Macati, mentioned by Cox,[10] is still in operation. The clay is obtained along the river near the plant. It lies near the surface, and very little labor is required to win it. The bricks are molded by hand by the soft-mud process. The workman throws a mass of the mud, about 30 centimeters in diameter, into a mold and cuts off the excess by means of a wire mounted on a frame. The clay is so sticky that the wet bricks are powdered with a black carbonaceous material, obtained by burning coconut husks, to facilitate handling and to prevent them from cracking during drying. A molder can make from one hundred to three hundred bricks per day. The bricks are allowed to dry from fifteen to twenty days in a large shed, where they are protected from the sun.

The kiln is very interesting and might be classed as a temporary, round, updraft kiln.[11] The front is permanent and is well constructed of masonry. Starting with this, for each burning, the bricks are built into the shape of a beehive and covered on the outside with clay. When the kiln is completed, it is from 3.5 to 4.5 meters high and from 6 to 8 meters in diameter. There is no grate of any kind, but a small wood fire is built on the floor of the kiln in a space left for the purpose at the time the bricks are placed in position. The combustion gases pass out through a small chimney and also through several small openings on the sides of the kiln. The fire is so small in comparison with the size of the kiln that a high temperature is never reached, and when the bricks are removed after two to three weeks, they have been little more than dried.

As a result, the product obtained is very inferior and could not be used in walls of any considerable height. Small pieces may be broken off with the fingers. However, the clay is a good material for making building brick when it receives the proper treatment. Some small test bricks were molded in this laboratory by the stiff-mud process. When burned to only cone 02 (1,110°), they developed a crushing strength of 393 kilograms per square centimeter. A number of tests have been made on this clay; they are given in Tables III and IV. It seems obvious that the poor quality of the product made at the San Pedro Macati factory is due to the process of molding and to insufficient burning. The clay seems better adapted to the stiff-mud process. A view of the kiln, while in use, showing the permanent front, is given on Plate I. The small fire in the foreground furnishes the only heat for the kiln. One of the workmen stated that the fire is maintained at about the same intensity during the entire burning. Plate II shows the molding and drying room.

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[9] In 1903 there were 27 establishments, employing 954 persons, engaged in the manufacture of brick and tile. See Census of the Philippine Islands. Government Printing Office, Washington (1903), 4, 516.

[10] *This Journal, Sec. A* (1907), 2, 428.

[11] See *Bull. Oklahoma Geol. Surv.* (1911), No. 7, 81.

A building-brick and floor-tile factory is located on Cebu Island, about 600 meters north of Mabolo barrio. The clay used (Tables III and IV, clay 1) is in some respects superior to clay 2. Apparently it is molded by the soft-mud process, though I did not see the operation. The kiln is similar to a drawing shown by Adams and Pratt.[12] The shape somewhat resembles a truncated cone placed in a horizontal position. It is 26 meters in length. At the small end the height is 1.15 meters and the width 0.85 meter, inside measurements. At the large end the height is 2.20 meters and the width 2.30 meters, inside measurements. There are three fire boxes: one at the small end and two at the sides. Wood is used for fuel, and the kiln seems to be efficient. As a result of a better raw material and a more efficient kiln, the product is much superior to the San Pedro Macati brick.

CHEMICAL AND PHYSICAL TESTS

While the primary object of the present work is to find a suitable material for the manufacture of paving brick, it is also desired to obtain as much information as possible about Philippine clays in general. Consequently all clays that have been received have been tested, though in some cases it was evident that the material was not the one sought. A number of the samples appear to be excellent building-brick materials, though it is difficult to decide finally on a clay until full-size bricks have been molded and subjected, as nearly as possible, to the processes that are to be used in the manufacture.

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[12] *This Journal, Sec. A* (1910), 5, 145.

SOURCE AND DESCRIPTION OF SAMPLES

1. About 600 meters north of Mabolo barrio, Cebu. Brown; good working qualities.
2. Pasig River, near San Pedro Macati. Brown; sticky.
3. Laguna Province, on the shore of Laguna de Bay, between Lumbang and Pagsanjan. Gray; plastic.
4. Masbate, white clay; analysis corresponds closely to kaolin.
5. Calapan, Mindoro. Dark brown; contaminated with stone.
6. Camansi, Cebu. A brown shale.
7. Near Jaro River, about 3 kilometers from Iloilo. Dark brown; slightly contaminated with stone.
8. Rio Grande de la Pampanga, Matamu barrio, Arayat, Pampanga. Dark brown; contaminated with sand.
9. Bangued, Abra subprovince, Ilocos Sur. A light red clay.

The chemical analysis of each sample as received is given in Table II.

TABLE II.—*Analyses of clays.*[a]

[Numbers give percentages.]

Determinations.[b]	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.
Loss on ignition	6.11	13.84	20.94	27.30	16.21	....	13.45	10.72	14.56
Silica (SiO_2)	74.53	51.00	44.00	37.80	46.20	44.35	51.64	56.10	51.90
Alumina (Al_2O_3)	13.17	20.60	26.66	34.20	27.56	24.90	19.52	18.24	24.20
Ferric oxide (Fe_2O_3)	2.14	6.36	4.34	0.40	3.50	....	6.06	6.92	7.14
Calcium oxide (CaO)	1.44	2.91	1.15	trace	2.80	11.37	4.14	3.74	0.54
Magnesia (MgO)	0.72	2.31	0.86	trace	2.50	2.59	3.74	2.64	0.79

[a] Most of these analyses were made by F. D. Reyes, inorganic chemist, Bureau of Science.

[b] Alkalies were not determined.

Methods of testing a raw clay.—There are a great many physical tests that can be applied to clays, but some of them are of doubtful value. In this work only those which are most important were chosen. In general, these are well known.[13]

Water of plasticity.—The clay is ground, put through a sieve having about 8 meshes per centimeter (20 per inch), and then mixed with sufficient water to give the right consistency. After a little experience this consistency can be determined by the working qualities of the clay. A small pat is made on a square of glass which has been previously weighed. The pat is dried at room temperature for several days and then for one day in an air oven at 105 to 110°C. It is removed from the oven and allowed to cool in a desiccator. The loss in weight is calculated to per cent on the basis of the dry weight. Clay of the same consistency is used in making the other tests described here, and the method of drying is the same.

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[13] I am indebted to Prof. A. V. Bleininger, of Ohio State University, for a number of suggestions, which have proved helpful in carrying out the physical tests.

Drying shrinkage.—The clay is molded in the form of a bar 2.5 by 2.5 by 15 centimeters. Two parallel scratches, one near each end, are made with a pair of dividers. The distance between them is measured and recorded. After the bar has been dried, the distance is again measured and the shrinkage calculated on the basis of the dry weight.[14]

Slaking time.—A 2.5-centimeter cube is molded and dried; it is placed in a small wire basket and immersed in water. The time required for complete disintegration is recorded as the slaking time.

Tensile strength.—In making the tensile-strength determinations the Fox method[15] was followed, in general. The clay is mixed with water and is allowed to stand for a day or two. It is then rolled out in the form of a thick slab and cut into briquettes with a cutter similar to a biscuit cutter. The clay is forced into the molds and pressed into shape, and the excess is removed by a spatula. After drying for several days at room temperature, the briquettes are thoroughly dried in an air oven and then kept in a desiccator until broken. The width and thickness of each briquette at the narrowest point is measured before breaking and the results are calculated to tensile strength per unit area.

The physical tests on the raw clays are given in Table III.

TABLE III.—*Tests of clays in raw state.*

No. and source of sample.	Water of plasticity.[a]	Linear drying shrinkage.[a]	Slaking time.	Tensile strength.		Drying qualities at room temperature.
				Kilos per square centimeter.[b]	Pounds per square inch.	
	Per cent.	*Per cent.*	*Minutes.*			
1. Mabolo, Cebu	23.26	3.75	34	24.2	345	Very good.
2. Pasig River	45.96	10.87	62	12.2	176	Good.
3. Laguna Province	59.00	14.29	3	nil	------------	Poor.
4. Masbate	59.97	9.09	65	nil	------------	Do.
6. Mindoro	36.91	11.11	8	nil	------------	Good.
5. Camansi, Cebu	30.96	10.05	13	21.7	308	Do.
7. Jaro River, Iloilo	37.46	13.21	6	5.8	83	Poor.
8. Pampanga	27.87	10.09	25	31.3	447	Good.
9. Abra subprovince	38.96	10.09	36	10.8	156	Do.

[a] Calculated to the basis of the dry weight.

[b] Average of six briquettes.

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[14] See *Bull. Oklahoma Geol. Surv.* (1911), No. 7, 37.

[15] See *Bull. Ill. State Geol. Surv.* (1908), No. 9, 163.

Burning tests.—The change in porosity of clays with increasing heat treatment is an important factor in determining their value for paving-brick manufacture. This test is considered by many to be the best that has been so far devised. The test in this laboratory is, in general, carried out according to the method used by Purdy.[16] A number of small bricks, 2.5 by 2.5 by 5 centimeters, are molded and thoroughly dried. They are then placed in a kiln in a row parallel with a row of Seger cones.[17] As each cone fuses, the corresponding brick is removed from the kiln, allowed to cool slowly, and then marked with the number of the cone. The heating is usually continued until the fusing point of the clay is reached or the specimens begin to crack badly. The burning tests described here were made in a small gasoline muffle kiln.

The test bricks are weighed and placed on end in distilled water, with the upper surface exposed to facilitate the escape of air. After remaining overnight, they are boiled in water under reduced pressure for about six hours. They are then removed from the water and reweighed. The suspended weight is taken by weighing each specimen while suspended in water. From these data the porosity may be calculated.[18]

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[16] *Bull. Ill. State Geol. Surv.* (1908), No. 9, 141.

[17] It is customary to give temperatures in terms of Seger cones, although it is well known that the fusing points of these cones depend to some extent on the rate of applying heat and on various other kiln conditions. [See, for instance, The melting points of pyrometric cones under various conditions, Geijsbeek, S., *Trans. Am. Cer. Soc.* (1912), 14, 849.] However, since the cones and the test piece are subjected to the same heat treatment, they are in general use in ceramic processes. The approximate fusing points of the cones employed in this work are here given:

Cone No.	Temperature, °C.	Cone No.	Temperature, °C.	Cone No.	Temperature, °C.	Cone No.	Temperature, °C.
010	950	03	1090	5	1230	12	1370
09	970	02	1110	6	1250	13	1390
08	990	01	1130	7	1270	14	1410
07	1010	1	1150	8	1290	15	1430
06	1030	2	1170	9	1310		
05	1050	3	1190	10	1330		
04	1070	4	1210	11	1350		

[18] Percentage porosity $= \frac{W-D}{W-S} \times 100.$

Where, W=wet weight, D=dry weight, S=suspended weight.

TABLE IV.—*Porosity of clays at various cones.*[a]

[Numbers give percentages.]

Clay No.	Porosity at cone No.—										
	010.	09.	08.	07.	06.	05.	04.	03.	02.	01.	1.
1	35.04	-------	36.20	-------	35.84	-------	35.36	-------	27.85	-------	29.02
2	36.87	-------	35.88	-------	32.67	-------	31.25	-------	31.56	-------	28.41
5	-------	21.25	-------	19.49	-------	18.89	-------	20.76	-------	19.10	18.32
9	-------	36.15	-------	35.92	-------	34.22	-------	29.33	-------	28.41	-------

Clay No.	Porosity at cone No.—									
	2.	3.	4.	5.	6.	7.	8.	9.	11.	13.
1	-------	-------	3.13	-------	-------	10.96	-------	18.24	15.22[b]	-------
2	-------	-------	10.91	-------	-------	17.71	-------	(c)	-------	-------
5	-------	17.72	-------	13.77	-------	(d)	-------	(e)	-------	-------
9	28.21	-------	27.68	-------	27.11	-------	26.75	24.41	1.97	8.97

[a] Clays not given here did not show burning qualities suitable for these data.

[b] Specimen very soft at cone 11.

[c] Commences to soften at cone 7; fuses at cone 9.

[d] Cracks to pieces at cone 7.

[e] Commences to vitrify at cone 9.

DISCUSSION OF RESULTS OF PHYSICAL TESTS

The behavior of the clays in all the tests except porosity is as follows. All comments are based on the behavior of the small test bricks and pats. It is planned to carry on tests on full-size bricks made from all clays which show any promise as paving-brick material.

No. 1. This clay is one of the most favorable of those which have been tested in this laboratory. It is easily molded and dries without cracking or excessive shrinkage or distortion. When placed in the kiln, all of the specimens from cone 010 to cone 11 are in good condition. It commences to vitrify at about cone 4 and does not begin to soften until cone 11 is reached. Two test bricks burned at cone 4 showed a crushing strength of 880 kilograms per square centimeter. The clay burns to a medium dark red up to the point of vitrification and then becomes a dark brown. The raw clay briquettes show a strength of 24.2 kilograms per square centimeter.

No. 2. This material should produce good building brick under the proper conditions of molding and firing, although higher in water of plasticity and drying shrinkage than clay 1. It dries well without cracks or distortion. The test bricks are a dark red until vitrification begins, then become almost black. It is likely that this clay would cause trouble in a large kiln, because the vitrification range is so short. It commences to vitrify at about cone 4 and is completely fused at cone 9. The tensile strength is much lower than that of clay 1 (12.2 kilograms per square centimeter).

No. 3. All the physical tests made indicate that this sample is worthless for either building or paving brick. It has a very high shrinkage, poor drying qualities, and practically no tensile strength. The test bricks crack to pieces in the kiln.

No. 4. This clay is very plastic and could not be used for any class of ceramic work unless it was mixed with some inert subtance. The test bricks crack to pieces on drying.

No. 5. The drying qualities are good. It does not crack, but warps to some extent. It has practically no tensile strength. It begins to vitrify at about cone 1, but cracks to pieces at cone 7. It seems to have none of the qualifications of a paving-brick material, but could possible be used in making building brick. Its usefulness for this purpose would depend largely upon the extent of its contamination with stone. If this contamination continues very far back from the outcrop, the labor required to purify it would probably be prohibitive for building-brick manufacture.

No. 6. Carbonates are present in sufficient quantity in this material to prohibit its use if fired above cone 03. The test bricks fired below that temperature seem satisfactory for building brick. If building brick were made of this sample and burned in a kiln heated with coal, considerable care would be necessary to avoid too high temperatures. The test bricks break up at about cone 03 on account of the evolution of carbon dioxide and fuse completely at cone 05. The tensile strength is 21.7 kilograms per square centimeter. The working and drying qualities are satisfactory. Some of the test bricks soaked in water overnight showed no signs of cracking or disintegration.

No. 7. There is some contamination of stone in this material, and its drying qualities are poor. It appears worthless for either building or paving brick. The test bricks lose shape before reaching cone 1.

No. 8. The working behavior and drying qualities of this material are good. The tensile strength of the briquettes is exceptionally high (31.3 kilograms per square centimeter). It seems satisfactory for building brick if burned at about cone 05. It has too low a fusing point for a satisfactory paving brick if worked alone. Its high tensile strength leads me to believe that it could be advantageously mixed with some inert siliceous material.

No. 9. In most respects this is one of the best clays tested. Its working and drying qualities, tensile strength, behavior in the kiln, and color are excellent. It should produce a building brick, satisfactory in color and structure. It does not begin to vitrify until about cone 9. This would be a considerable advantage in making building brick, because the temperature would not have to be so carefully controlled as with a clay having a low fusing point. Unfortunately, however, the material could not be economically used for paving brick on account of the high temperature that would be necessary in the kiln.

Temperature-porosity data.—Of the samples tested so far, only Nos. 1, 2, 5, and 9 show burning qualities suitable for plotting temperature-porosity curves. The curves for these samples are shown on fig. 1.

Only one of them (No. 1) is apparently suitable for paving brick. Nos. 2 and 5 have short vitrification ranges, and No. 9 has a vitrification temperature too high for practical purposes. Clay 1 corresponds, in general, in chemical analysis and most of the physical tests to some materials now being used for paving-brick manufacture in the United States.

TABLE V.—*Chemical analyses and some physical tests of a number of clays used in the manufacture of paving brick in the central part of the United States.*[a]

Sample No.	Moisture.	Loss on ignition.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3).	Magnesia (MgO).	Calcium oxide (CaO).	Potassium and sodium oxides (K_2O, Na_2O).	Tensile str'gth of raw clay per square centimeter.	Linear shrinkage.	Water of plasticity.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Kilos.*	*Per ct.*	*Per ct.*
1	0.50	8.18	60.89	16.40	8.20	1.61	0.55	4.15	5.038	2.10	14.40
2	0.27	3.54	68.50	16.98	5.77	1.71	0.99	2.97	4.023	0.90	13.40
3	0.81	7.02	58.35	18.09	6.14	2.03	1.20	4.58	12.503	5.82	19.60
4	1.02	10.45	55.18	19.22	8.19	1.67	0.56	2.85	9.094	3.25	15.23
5	0.60	10.09	54.37	23.61	6.14	1.61	1.58	2.78	22.586	3.60	13.35
6	0.43	7.97	57.09	19.07	7.92	1.91	0.80	4.69	7.529	3.30	16.30
7	1.29	8.08	58.42	25.05	3.04	1.52	0.46	2.30	10.025	4.50	13.40
8	0.68	4.86	63.41	18.61	5.82	1.16	0.41	3.60	8.527	3.30	13.00
9	1.06	5.95	58.57	20.40	7.40	1.37	0.63	3.27	4.996	3.00	13.30
10	0.02	8.00	55.51	21.81	7.66	1.63	0.56	3.56	5.032	3.20	13.20
11	0.83	9.40	55.02	20.35	6.26	1.70	0.87	3.64	9.071	2.70	17.20
12	0.79	4.39	56.29	20.32	7.90	2.01	0.48	4.46	9.882	4.20	16.60
13	3.05	6.70	60.31	19.11	6.14	1.73	2.73	1.44	9.208	5.00	17.70
14	0.86	5.14	63.42	16.24	6.62	1.87	1.64	4.83	8.634	1.94	11.80
15	1.49	7.01	56.25	18.79	8.02	1.33	2.39	4.60	14.174	5.50	16.50
16	1.57	5.08	68.15	12.89	7.52	0.59	1.02	2.93	13.062	4.20	14.40
17	0.98	6.75	62.70	16.95	8.98	1.47	1.17	3.03	9.865	4.60	16.50
18	2.55	6.66	58.62	17.74	8.48	0.98	1.26	3.92	8.526	3.70	16.40

[a] *Bull. Ill. State Geol. Surv.* (1908), No. 9, 285, 287.

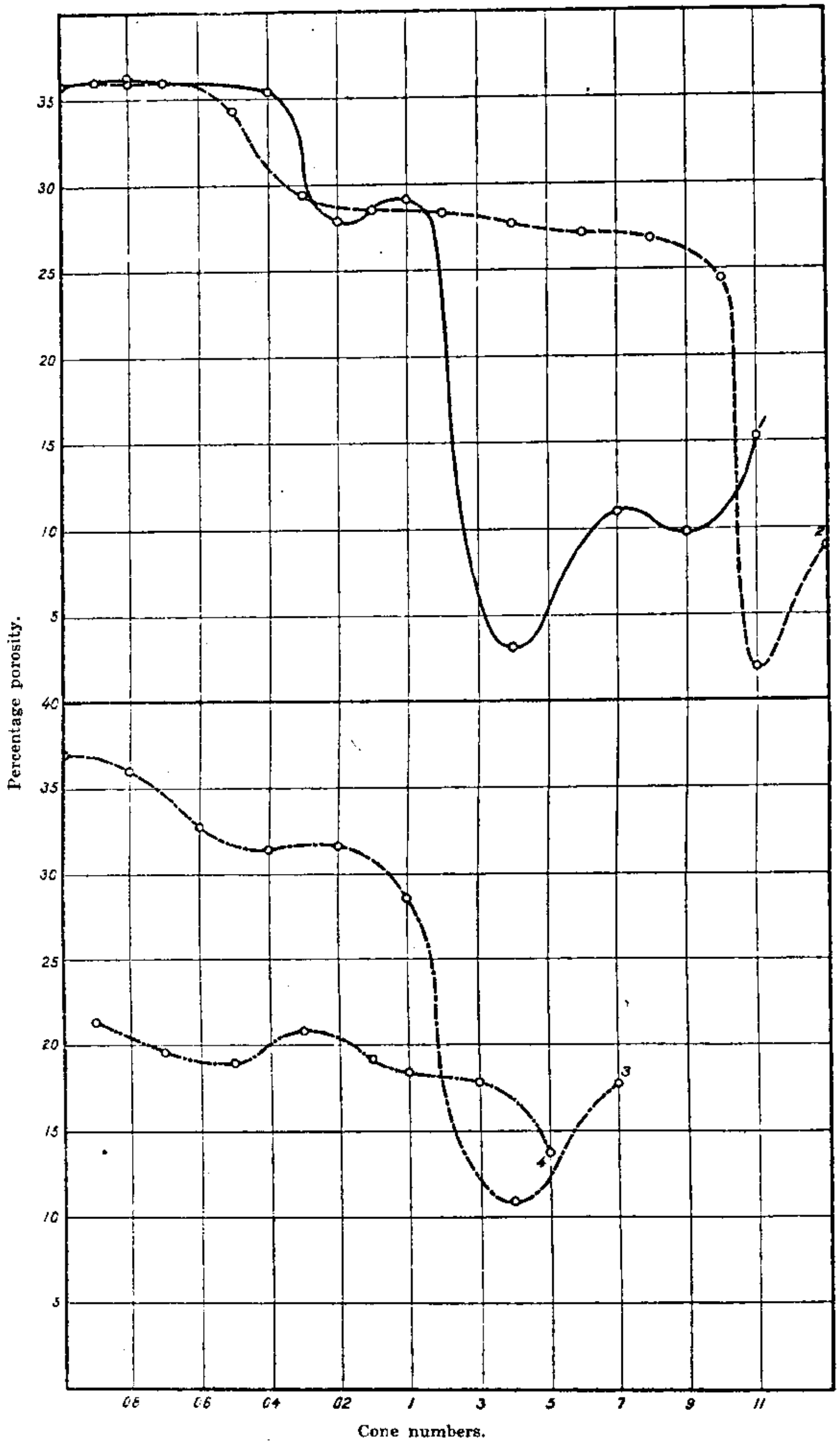

FIG. 1. Showing temperature-porosity curves for paving-brick materials. Curves 1, 2, 3, and 4 represent clays 1, 2, 5, and 9, respectively.

The geologic collection of the Bureau of Science contains many samples of clays and shales. Recently I have looked over these samples in a search for suitable paving-brick materials. The ones that show a lack of plasticity, or are too high in carbonates, have been given no further consideration. On other samples as much material as could be removed without destroying the specimens was taken and made into pats. Some idea of the working and drying qualities of the clays was obtained from these. Several of the more satisfactory pats were placed in a kiln to obtain some idea of their burning qualities. A list of the clays represented by these specimens and the locations of deposits as accurately as is known are given in Table VI. An effort will be made to obtain larger samples of the favorable materials.

TABLE VI.—*Samples of clays and shales in Bureau of Science geologic collection.*

[This includes only those which are plastic and which contain no carbonates.]

Location of deposit.		Material.	Appearance of raw-clay test pieces.	Probable value.
Town and province.	Additional information.			
Batan, Batan Island.	Entry No. 2, Bett's claim, between coal seams.	Shale	Gray	Very good.[a]
San Jose, Camarines	River north of Sabang.	do	Light brown, no strength.	
Colasi, Antique	Maralison Island	Kaolin	Gray, no strength	
Antique Province		do	do	
Los Baños, Laguna		do	White, no strength	
Angat, Bulacan	Maon Creek, pyrite veins.	Clay	Gray	Fair.[c]
Do.	Mayapo	do	White, no strength	
Surigao Province	Eugenio's house	Shale	Brown	Fair.[c]
Isabela Province	Cagayan Nuevo mine	Clay	White, no strength	
Tagonton, Camarines	San Mauricio mine	Kaolin	do	
Magalang, Pampanga	San Agustin	Clay	do	
Paracale, Camarines	Trinidad mine	Kaolin	Light brown, no strength.	
Nagcarlang, Laguna		Clay	Light brown	Possible.[c]
Bucay, Abra		Kaolin	White, little strength	
Mindoro Province		Clay	Light brown, little strength.	
Batac, Ilocos Norte		do	do	
La Union Province	Cruz Mountains	Shale	Brown	Fair.[a]
Nasugbu, Batangas	East of town	Clay	White, no strength	
Matiquio, Laguna		do	Light gray, little strength.	
Alphonso, Palawan	Balabac Island	do	Reddish brown	Fair.[c]
Manito, Albay		do	Gray	Possible.[c]
Magpog, Mindoro		Kaolin	White, little strength	

[a] Vitrified below cone 7. [b] Fused below cone 7. [c] Did not vitrify below cone 7.

TABLE VI.—*Samples of clays and shales in Bureau of Science geologic collection*—Continued.

Location of deposit.		Material.	Appearance of raw-clay test pieces.	Probable value.
Town and province.	Additional information.			
Los Baños, Laguna	Alpha mine	Clay	White, little strength.	
Santa Mesa, Rizal	Pasig River	do	Gray	Very good.[a]
Bulalacao, Mindoro	Mahohao River	Shale	Very dark gray	Very good.
Bannangan, Benguet	First hills on road to Baguio.	Clay	Light brown, little strength.	
Los Baños, Laguna		Kaolin	do	
San Remigio, Antique		Clay	Gray	Very good.[b]
Compostela, Cebu	Cotcot River	Shale	Brown	Fair.[c]
Tiwi, Albay	Tigaboc	Kaolin	White, no strength	
Bataan Province	Trail between San Jose and Mariveles; elevation, 106 meters.	Clay	Gray, little strength	
Cebu Province	Near Baliana	Shale	do	Possible.
San Fernando, Capiz, Sibuyan.	Mabolo	Kaolin	Gray, no strength	
Los Baños, Laguna		Clay	White, no strength	
Baguio, Mountain	Kelly's mine	do	Gray, little strength	Possible.
Bamaoto, Sabagan, Mountain.	Outcrop along trail	Shale	Gray, fair strength	Fair.
Placer, Surigao	Lagondola	Kaolin	White, very good strength.	

[a] Vitrified below cone 7. [b] Fused below cone 7. [c] Did not vitrify below cone 7.

BONDING QUALITIES OF PASIG CLAY

There is a large tuff quarry not far from the clay deposit on Pasig River (clay 2), and it was decided to investigate the properties of mixtures of the clay with pulverized tuff. The clay is not satisfactory for paving brick when used alone, but it seemed probable that the mixture of the two substances might be satisfactory. A large sample of the tuff was secured and ground to about 20 mesh. Some of the Pasig clay was dried and ground to the same fineness. The two were mixed in various proportions and from each mixture tensile-strength briquettes and some experimental bricks for fire test were made. Mixtures containing up to 70 per cent tuff exhibited very satisfactory working and drying qualities. The average tensile strengths of the various mixtures is shown in Table VII. All the briquettes were made in the same manner and carried through in parallel until broken.

TABLE VII.—*Bonding power of Pasig clay.*

Mix.		Tensile strength.	
Clay.	Tuff.	Kilos per square centimeter.	Pounds per square inch.
Per cent.	*Per cent.*		
100	0	12.2	176
80	20	8.0	115
70	30	9.2	132
60	40	8.3	118
50	50	10.5	149
40	60	10.5	151
30	70	10.2	147

It is surprising that the tensile strengths of all the mixtures were nearly alike. One might expect that the strength would be less with the lower percentages of clay, but the results obtained show that this is not the case. The general behavior of the various mixtures leads me to believe that most of them could be used in the manufacture of building brick; but unfortunately the results of the fire tests were such as to eliminate them from consideration as paving-brick materials. This is because the vitrification range is too short. In fact, the test pieces fused almost as soon as they commenced to vitrify. The disadvantage in making building brick from a mixture is the labor required to dry and pulverize the two materials.

SUMMARY

1. There is an urgent need, in the Philippines, for a suitable paving material for city streets. Imported materials are not generally available for this work on account of prohibitive freight rates.
2. The Bureau of Science is searching for a clay or a shale suitable for the manufacture of paving brick. Tests on nine samples have been completed.
3. The success of the undertaking depends, to a large extent, on coöperation in securing samples. If a sufficient number can be obtained, it seems likely that the right deposit may be located.

ILLUSTRATIONS

PLATE I

FIG. 1. Kiln at San Pedro Macati brick factory.
2. Molding and drying room at San Pedro Macati brick factory.

TEXT FIGURE

FIG. 1. Chart, showing temperature-porosity curves for paving-brick materials.

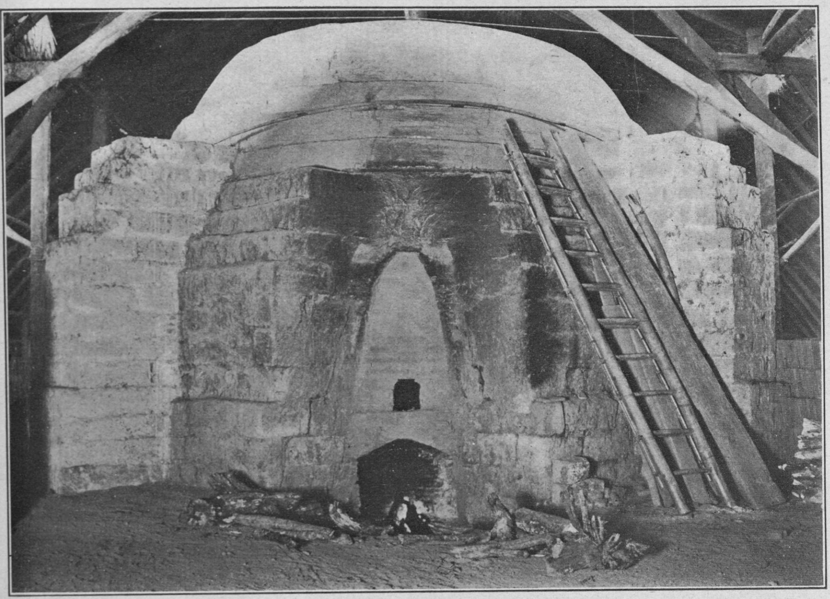

Fig. 1. Kiln at San Pedro Macati brick factory.

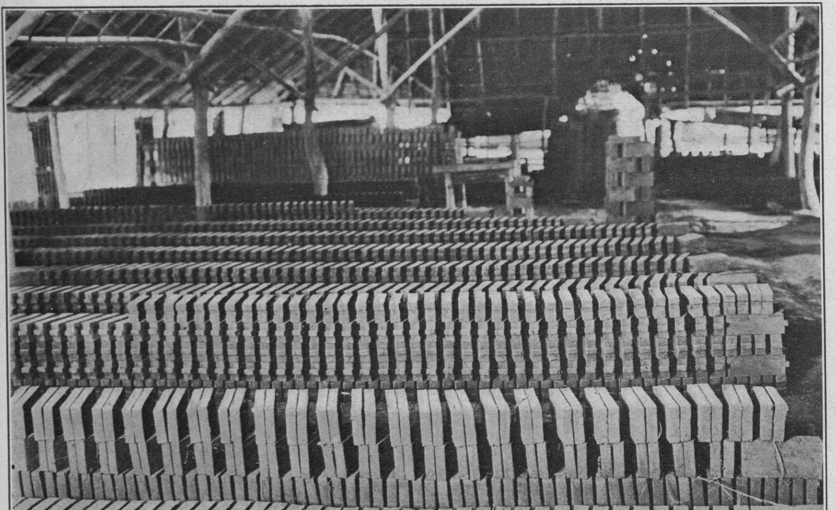

Fig. 2. Molding and drying room at San Pedro Macati brick factory.

PLATE I.

PHILIPPINE LAKES

By WALLACE E. PRATT

(From the Division of Mines, Bureau of Science, Manila, P. I.)

ONE PLATE AND 2 TEXT FIGURES

INTRODUCTION

An incomplete list of Philippine lakes appeared in 1900,[1] and brief notes on different lakes have been recorded in various geographic and geologic studies of the Philippines, but these observations have not been assembled in collected form. The Bureau of Science recently received a request from a European geographic journal, compliance with which necessitated a compilation of the existing data with regard to lakes in the Philippine Islands. In order that the information brought together for this purpose might be made more widely available locally, it was prepared for publication in this Journal.

The origin of most of the lakes in the Philippines is closely related to volcanic and seismic activity. A number of smaller lakes occupy the craters of extinct volcanoes; others owe their existence to subsidence and differential vertical movement resultant upon volcanic activity or to the obstruction of drainage courses by lava flows and by fragmental volcanic ejecta. In the central valley of Luzon, along Cotabato and Agusan Rivers in Mindanao, and in other low-lying areas in the Archipelago, more or less permanent bodies of water are encountered which probably occupy abandoned portions of the courses of shifting rivers and low areas between the alluvial flood plains of adjacent, parallel streams.

Among the forty or more lakes which are known in the Philippines only three, namely, Laguna de Bay or Lake Bay in Luzon, Lake Bombon or Taal in Luzon, and Lake Lanao in Mindanao, stand out prominently because of their size or economic importance. On the other hand, because of the importance of fish in the diet of the average Filipino, districts in which lakes occur, even in the cases of small lakes in isolated regions, have always been better known to the people than the surrounding inland country.

[1] El Archipiélago Filipino. Washington (1909), 2, 439.

LAKES OF LUZON

It will be convenient in description to group the lakes according to the islands upon which they occur and to take them up for discussion under these heads in the order of their importance.

LAGUNA DE BAY

The largest and most important lake on Luzon is Laguna de Bay. Lake Bay, the English equivalent for the Spanish name, has never come into general use, although the other lake names have been almost universally anglicized.[2] Laguna de Bay lies in the center of southern Luzon, immediately southeast of Manila. It is more than twice as large as any other Philippine lake, and excluding the area of Talim Island, it covers 930.7 square kilometers according to the Director of the Coast and Geodetic Survey. It is uniformly shallow, the deepest soundings recorded being 6.5 meters. The floor of the lake is level, and the immediate shores are low around most of the perimeter, but both east and west of the lake walls of tuff rise abruptly a short distance from the water's edge, and on the south the lake encroaches upon the foot of Mount Maquiling, an extinct volcano. The lake, whose surface fluctuates but seldom, rises more than 2 meters above sea level, receives drainage from numerous small streams on all sides, and is drained in turn by Pasig River, which cuts through the moderately low table-land of volcanic tuff on the west to Manila Bay. In outline Laguna de Bay is irregular; two rather slender but mountainous areas of flows, tuffs, and agglomerate—Jalajala Peninsula and Binangonan Peninsula with its southern continuation in Talim Island—protrude from the northern border dividing the northern half of the lake into three lobelike parts.

George I. Adams[3] reviews the various theories that have been advanced to explain the origin of Laguna de Bay. The early suggestions that it occupies a former crater or that it was formed through the subsidence of a volcano do not find general support. The idea that it was once an arm of the sea is generally accepted, but there is a difference of opinion as to the manner in which its impounding was accomplished. R. von Drasche[4] thought that an eruption of Taal Volcano was responsible for the separation of the lake from the sea, while Becker[5] explained its isolation from the rest of the Central Plain of Luzon as the result of a slight undulation in surface. Adams[6] argues with considerable reason that the position of the lake marks a fault line which extends in a general north-south direction and that the escarpment of tuff to the west of the lake represents one face of a raised fault block which has retreated to the west through erosion. The elevation of the block on the opposite side of this fault separated the lake from Manila Bay, but was gradual enough to permit the erosion of the outlet through Pasig River.

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[2] The explanation of the persistence of the name Laguna de Bay is undoubtedly to be found in the anomaly which is involved in the term Lake Bay, because of the application of the English word "bay" to bodies of water other than lakes.

[3] *This Journal, Sec. A* (1910), 5, 103.

[4] Fragmente zu einer Geologie der Insel Luzon (Philippinen). Gerold's Sohn, Wien (1878).

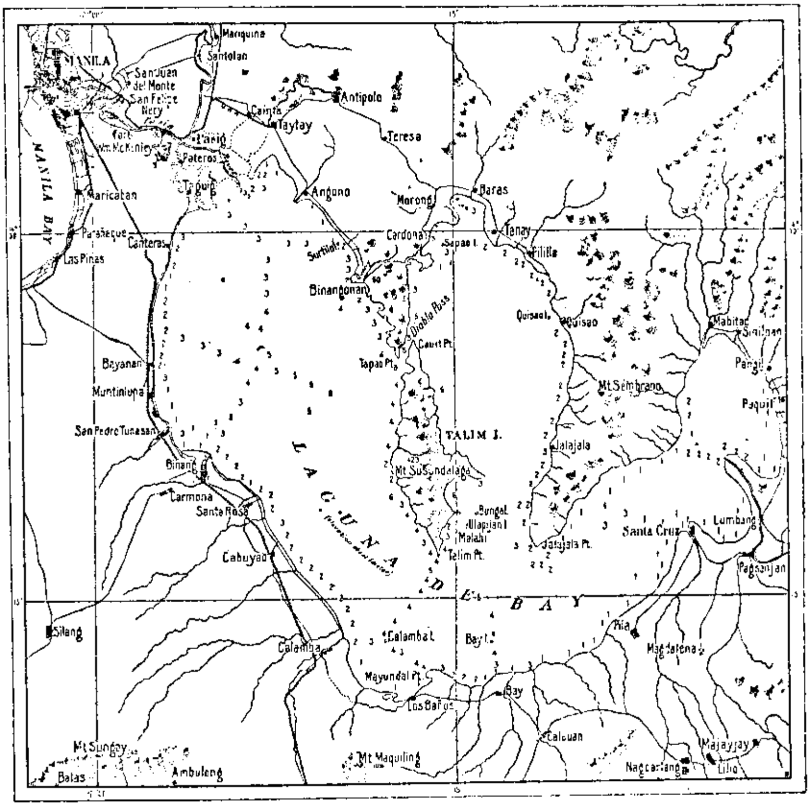

FIG. 1. Laguna de Bay, southwestern Luzon. (Depths and elevations are given in meters.)

It is said that the former town of Bay on the southern shore of the lake occupied a position which is now submerged, indicating subsidence in that region; likewise the lake is believed to be encroaching at the present time upon the land near Calamba on its southwest shore. To the north and northeast, on the other hand, there are considerable areas of low, flat country which were probably at one time a part of the lake floor, but have emerged through slow elevation.

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[5] Geology of the Philippine Islands, *21st Annual Rep. U. S. Geol. Surv.* (1901), reprint, 77.

[6] Op. cit., 97.

Laguna de Bay is important as a waterway, and steamers ply constantly between Manila and the towns about its perimeter. It supports an extensive fishing industry, and there are rich agricultural communities on the low lands near its shores.

LAKE BOMBON OR TAAL

Taal Lake is situated in southwestern Luzon to the south of Laguna de Bay. It is roughly oval in outline, and the active volcano Taal forms an island some 25 square kilometers in area near its center; several smaller islands lie to the east of the volcano. Taal Lake has an area of 267.5 square kilometers and is comparatively deep; in its southeastern portion maximum soundings of 177 meters are recorded by the Coast and Geodetic Survey. In 1909 the surface of the lake was 2.13 meters above sea level; it varies only slightly from this mean altitude. Only small streams enter the lake, but the outlet, Pancipit River, which empties into the sea at Lemery about 8 kilometers southwest of the southern shore of the lake, has a flow of considerable volume. The land surrounding Taal Lake on the north and west slopes generally away from the lake as a center and is made up of nearly horizontal beds of water-laid volcanic tuff; walls of this material rise to an elevation of several hundred meters and closely encircle that part of the lake. On the southeast where the lake is deepest it washes the foot of Mount Macolod, an andesite peak which is 958 meters high. Elsewhere about the lake the shores rise more gradually.

Several early investigators acquiesced in the idea that Taal Lake resulted from the collapse of a volcanic cone. Becker[7] discusses this theory, but inclines to the belief that the lake was formed through an explosive eruption of a former great volcano, a gigantic predecessor of the modern Taal, rather than through collapse, the occurrence of which he considers improbable. The former existence of a volcano of great size on the site of Taal is argued by Becker and others from the presence of the abrupt walls surrounding the lake and the relatively high areas of tuff to the north and west, which are taken to represent the outer slope of the old cone. Centeno calculated the height of this

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[7] Op. cit., 53.

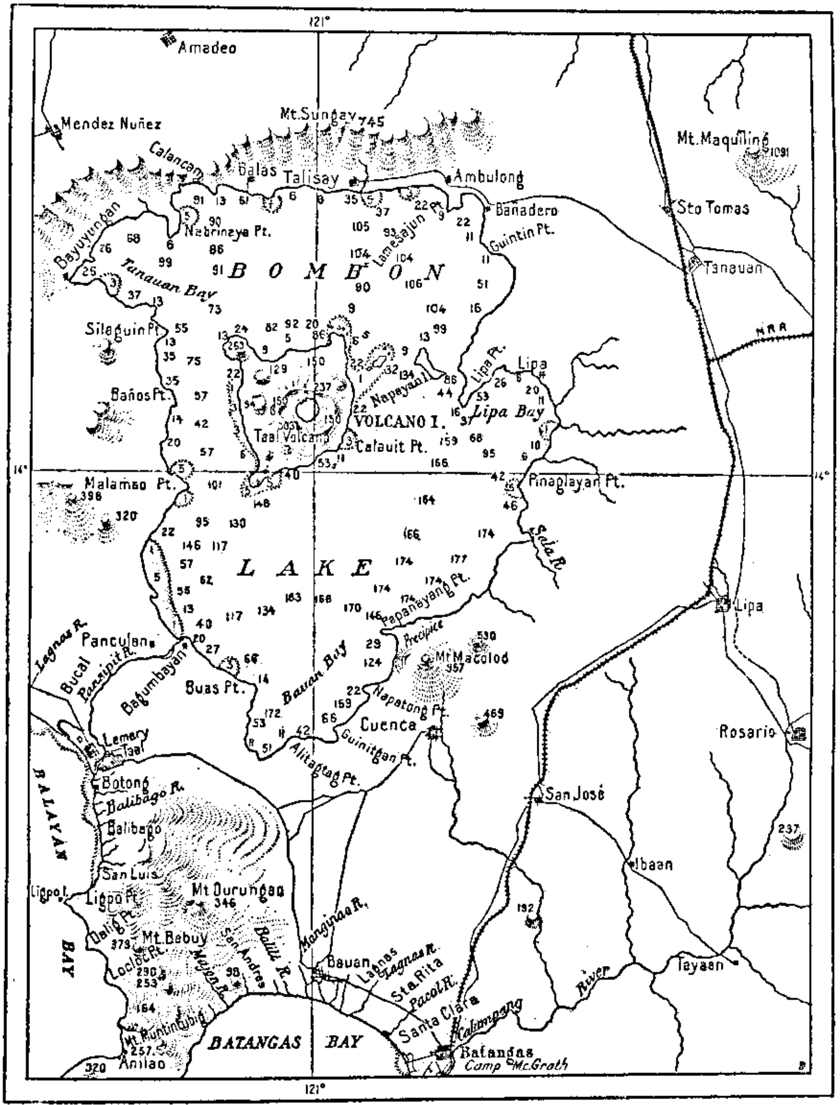

FIG. 2. Bombon, or Taal, Lake, southwestern Luzon. (Depths and elevations are given in meters.)

former volcano at 3,750 meters. Adams[8] points out that the volcanic tuff region which had been interpreted as part of the contour of the former cone is too nearly level to have been part of a former cone and concludes that the elevation of the tuff could be explained more rationally as part of a raised fault block. Mount Macolod on the southeastern shore of the lake, which had also been considered as a part of the former volcano, Adams found to be an eruptive mass unlike the fragmental tuff on the other side of the crater and, therefore, not reasonably to be accepted as part of the old cone. He accounts for the lake as the result of peripheral faulting and subsidence around a volcanic center which contained a number of vents, as evidenced by historic eruptions in which activity manifested itself at several points in the lake.

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[8] Op. cit., 102.

The water in Taal Lake has a slightly brackish taste. The following analysis, published by Cox,[9] represents the composition of a sample taken in 1905:

TABLE I.—*Analysis of water from Taal Lake.*

	Parts per million.
Silica (SiO_2)	31.5
Iron (Fe) and aluminium (Al)	4.2
Calcium (Ca)	53.4
Magnesium (Mg)	49.4
Sodium (Na)	456.3
Sulphuric ions (SO_4)	191.3
Chlorine (Cl)	720.0

Volcano Island and the shores of Taal Lake formerly supported a large population of fishing and agricultural people, but since the eruption of Taal Volcano in 1911, when 1,335 people were killed, permanent habitations are not permitted on the island nor around parts of the lake perimeter.

In connection with Taal Lake the crater lake within the volcano should be mentioned. Prior to the eruption of 1911 the crater of Taal Volcano contained several small lakes of hot water, one of which was always boiling. After the eruption, however, a single lake about 1 kilometer in diameter occupied the crater. When the first descent into the crater was made following the eruption, the surface of this lake stood 70 meters below sea level,[10] but subsequently it rose until at the present time it is about at sea level. The water of this lake is hot (boiling at places) and highly mineralized as is shown by the following analysis by Cox.[11]

[9] *This Journal, Sec. A* (1911), **6**, 96.
[10] Ibid. (1911), **6**, 78.
[11] Loc. cit.

TABLE II.—*Analysis of water from crater of Taal Volcano.*

	Parts per million.
Silica (SiO_2)	710.8
Iron (Fe)	172.0
Aluminium (Al)	26.1
Manganese (Mn)	79.9
Calcium (Ca)	556.8
Magnesium (Mg)	909.3
Potassium (K)	237.4
Sodium (Na)	2,584.3
Lithium (Li)	none.
Sulphuric ions (SO_4)	2,732.0
Phosphoric ions (PO_4)	none.
Metaboric ions (BO_2)	small.
Arsenic ions (AsO_4)	small.
Chlorine (Cl)	6,024.3
Bromine (Br)	trace.
Iodine (I)	none.

LAKE BATO

Lake Bato, in southeastern Luzon, is a permanent body of water, roughly circular in outline, which is situated in the wide valley of Bicol River between Camarines and Albay Provinces. It is very shallow, and its surface stands only a few meters above sea level. Its area varies with the season and averages about 25 square kilometers. A great part of the surface is covered by vegetation, and the margins of the lake are low and marshy. Fish are abundant, and the lake is especially noted for the numbers of waterfowl which live in the vegetation-covered portions. It appears that Lake Bato was formed through slight elevation connected with Isarog Volcano, across the base of one slope of which the outlet of the lake, Bicol River, flows.[12]

LAKE BUHI

Lake Buhi, in the southern part of Camarines Province, is of peculiar interest because of the accounts of its origin, for this lake is alleged to have formed within historic times. It lies in mountainous country southeast of Mount Iriga, one of the several volcanic peaks which dominate the physiography of southeastern Luzon. The lake covers an area of 13 square kilometers and is irregular in outline. No soundings are recorded for Lake Buhi, but it is probably deep for its size; the surface is 75 meters above sea level.

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[12] Adams, Geo. I., and Pratt, Wallace E., *This Journal, Sec. A* (1911), 6, 457.

Lake Buhi is said to have formed during an eruption of Mount Iriga in 1641. As quoted by Jagor,[13] from Estado Geografico, the account is as follows:

> I was informed by the priests of the neighboring hamlets that the volcano (Iriga) until the commencement of the seventeenth century had been completely conical and that the lake (Buhi) did not come into existence until half the mountain fell in at the time of its great eruption. This statement I found confirmed in the pages of Estado Geografico "On the 4th day of January, 1641—a memorable day—for on that day all the known volcanoes began to erupt at the same hour—a lofty hill in Camarines inhabited by heathen fell in, and a fine lake sprang into existence upon its site. The then inhabitants of the village of Buhi migrated to the shores of the new lake, which on this account was henceforward called Lake Buhi."

A section of the otherwise nearly perfect cone of Mount Iriga, on the side next to Lake Buhi, has been removed, and great blocks and fragments that might well have been parts of the missing section are scattered across the valley below the lake. The outlet of the lake, which empties into Bicol River, flows across this fragmental material in a series of falls and rapids, and it seems probable that the stream has been obstructed by fragmental ejecta from Mount Iriga. Lake Buhi is certainly too deep, however, to have originated from the obstruction in the river. If the historic account of the origin is to be credited, there must have been at the same time a subsidence in the area now occupied by the lake.

OTHER LAKES OF LUZON

Among the lakes of Luzon that are yet to be described, those of larger area are fluctuating bodies of water which occupy swampy places and abandoned river courses in the low-lying river valleys. In the central valley of Luzon there are several lakes of this character, among which may be mentioned Candaba swamp in Pampanga Province close to the boundary with Bulacan Province; Lake Canaren in Tarlac Province near the boundary with Nueva Ecija Province; an unnamed swamp near Hagonoy, Bulacan; and another swamp near Bayombong, Pangasinan. Adams[14] accounts for Candaba swamp, which covers an area of some 50 square kilometers during flood season, as an area lying between the main channels of Pampanga and Quingua Rivers which has failed to receive sufficient sediments to build it up as rapidly as the adjacent portions of the delta region. A swampy area in Cagayan Province in northern Luzon, similar in character to the lakes of the Central Plain, is known as Lake Cagayan; it lies but little above sea level and is said to cover an area of more than 100 square kilometers.

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[13] Reisen in den Philippinen. Wiedmann'she Buchhandlung, Berlin (1873), 109.

[14] Op. cit., 75.

Lake Paoay is situated in Ilocos Norte Province and is separated from the sea by a low, narrow barrier of wind- and water-borne sand. Its area, according to the Director of the Coast and Geodetic Survey, is 4.06 square kilometers and its maximum depth about 10 meters. No streams discharge into it or flow from it, and its level must be very nearly that of the adjacent sea.

A number of small crater lakes in southwestern Luzon should be mentioned to complete the list for this island. The volcanic region in which these lakes are found is marked by numerous cinder cones, and the lakes occupy the small craters around which these cones were built up. Thirteen such crater lakes are shown on Adams's reconnaissance map of southern Luzon, no one of which is more than 1 kilometer in its greatest dimension. They are most numerous immediately south of Laguna de Bay and are found as far west as the town of Nasugbu. A crater lake near the town of San Pablo has acquired a reputation locally as a point of scenic interest.

LAKES OF MINDANAO

Next to Luzon, Mindanao is of most importance in a study of Philippine lakes. Smith[15] enumerated thirteen lakes in his study of the physiography of Mindanao, and it appears that his list was not complete.

LAKE LANAO

Lake Lanao, in the Lanao upland region of central western Mindanao, is the second large lake in the Philippines and is the only large body of water at any considerable elevation. According to the Director of the Coast and Geodetic Survey Lake Lanao has an area of approximately 347 square kilometers and its surface is 700.4 meters above sea level. Its outline is irregular, but is slightly elongated from northeast to southwest. Soundings made in 1904 by engineers of the United States Army in the southeastern portion of the lake revealed a depth ranging from 78 to 112 meters; several harbors are utilized in the lake shipping, and depths of 2.7 to 4.6 meters are recorded for the water alongside. No soundings have been made in the center of the lake. The lake is drained by a single stream, Agus

[15] *This Journal, Sec. A* (1910), 5, 356.

River, which flows north into Iligan Bay over a distance of 24 kilometers. Agus River is swift-flowing and forms an important cascade in Maria Christina Falls, where the water makes an uninterrrupted plunge through a vertical distance of 58 meters. No large stream flows into the lake.

Lake Lanao is a center of Moro population. Two American military posts are located on its shores, and there is considerable traffic across it. The Spanish Government maintained a small gunboat on Lake Lanao as a part of the military operations against the Moros.

Smith [16] believes that Lake Lanao was formed by the damming of a basin between two mountain ranges, by flows of lava, and by accumulations of wash. The lake shores rise abruptly on the south, but on the north there is only a gentle upward slope for some distance from the water's edge, followed by an abrupt drop of 50 meters or more to the north, making a terrace which Smith designated as the Keithley escarpment.

LAKE MAINIT

Lake Mainit, on Surigao Peninsula in northern Mindanao, is a fresh-water lake, roughly circular in outline, that covers an area of about 75 square kilometers. Montano estimated that its surface stood 40 meters above sea level; and Father Francisco de P. Sanchez, a Jesuit missionary who visited Lake Mainit in 1889, found its greatest depth to be 150 meters. The surrounding country is mountainous. The outlet, Tubay River, reaches Butuan Bay only after a long detour to the south.

Lake Mainit has been considered as a crater lake by some observers, and thermal springs occur around part of its perimeter, especially near the village of Mainit on its northern shore. Smith states that possibly it is a caldera. However, limestone is found on the eastern shore, a fact which would make it seem improbable that the lake occupies a former crater. Maurice Goodman crossed Lake Mainit during reconnaissance in Mindanao and it did not appear to him to be a crater lake, although he thinks it probable that volcanic activity may be responsible for its existence.

I visited Lake Mainit in March, 1915. It is a beautiful body of water surrounded by mountains, except on the northern side, where there is a wide border of rich, low-lying, agricultural land. The records of the Jesuit fathers show that the lake rose approximately 4 meters in 1891 and flooded some of the villages on its northern shore. It is said to be subjected to fierce gales at short notice, and the native boatmen are wary about venturing upon it at certain seasons of the year. Fish are especially numerous in Lake Mainit, and immense colonies of wild ducks and other waterfowl make their home on its water. Crocodiles, also, are said to be especially numerous in this lake.

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[16] Op. cit., 353.

OTHER LAKES OF MINDANAO

The only other lakes in Mindanao that are of the same order of magnitude as Lake Mainit are swampy areas in the valleys of the larger rivers. In the valley of Mindanao River, inland from Cotabato, are three such bodies of water—Liguasan marsh, Libungan marsh, and Lake Butuan. Liguasan marsh covers an area of more than 100 square kilometers generally, but is subject to overflow during the rainy season; Libungan marsh is somewhat smaller. Lake Butuan covers an area of approximately 59 square kilometers and is from 3 to 6.4 meters deep, according to the Director of Coast and Geodetic Survey. These bodies of water are only slightly above sea level, and their surfaces are largely covered by aquatic vegetation. Smith[17] considers them to be remnants of a larger lake which formerly covered the intervening low country.

Lakes Dagum, Dinagat, and Linao and other adjacent smaller lakes occupy a swampy area in the upper valley of Agusan River in northeastern Mindanao. During flood periods these lakes become one body of water—always shallow (30 meters, maximum depth), but several hundred square kilometers in area. Their level is very little above that of the sea. They are said to have formed within historic times from subsidence or differential elevation following earthquakes. Such an origin is possible, since earthquakes are especially frequent and severe in Agusan Valley, but it is worthy of note in this connection that a large lake, Laguna de Mindanao, is shown on the upper Agusan on a map published as early as 1734.

Lake Leonard Wood lies north of Dumanquilas Bay in Zamboanga district at an elevation of 889 meters. The existence of this lake was first reported to the American administration by Captain C. C. Smith, Fourteenth Cavalry, United States Army, who explored it in 1904 in the course of an expedition from Misamis to Dumanquilas Bay. It is said to be like the figure eight in outline and 3 by 8 kilometers in maximum dimensions; its area is probably 20 square kilometers.

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[17] Op. cit., 356.

An unnamed lake about equal in size to Lake Leonard Wood is shown upon several maps of Mindanao near the head of Tagun River in Davao district, east-central Mindanao. The surrounding country is unexplored, and no details concerning the lake are available.

Lakes Munay, Dapao, and Nonugan are small bodies of water in the vicinity of Lake Lanao. Lake Munay has an area of 1 square kilometer and lies at an elevation of 700 meters; Lake Dapao has an area of 2 square kilometers and is 628 meters above sea level; Lake Nonugan has an area of 1 square kilometer and is 768 meters above sea level. According to Smith these lakes occupy local depressions on the surface of the basalt flows which cover the region in which they are found.

Smith observed two lakes, Malanao and Balut, near Cotabato and another, Lake Butig, in southeastern Davao, each of which seemed to him to occupy structural valleys, or synclines, in the locally folded sedimentary rocks. While these lakes are small and unimportant, they are worthy of note because of the unique origin ascribed to them. Nowhere else in the Philippines have lakes resulted from the folding of the bedded rocks.

A small lake called Majubdam was encountered by Father Sanchez on the slopes of Mount Maniayao above and to the north of Lake Mainit; its area is 0.1 square kilometer.

LAKES OF MINDORO

Lake Naujan, near the northeastern coast of Mindoro, is the only known lake on this incompletely explored island. Lake Naujan covers an area of about 70 square kilometers; in outline it is elongated from north to south, its surface dimensions being 7 by 14 kilometers. The Director of the Coast and Geodetic Survey estimates its elevation as 20 meters above sea level and its greatest depth as 15 meters. The outlet is to the north through Lumangbayan River. No large stream flows into the lake.

Lake Naujan is probably related in its origin to volcanic activity, although it does not appear to be a crater lake. The eastern shore is precipitous, but to the west the land rises gradually through vegetation-covered shallow water and swamps. The outlet has cut a fairly deep valley around the base of a hill which is probably of volcanic origin. Mr. A. L. Day, who spent a season on Lake Naujan collecting zoölogical specimens, found a number of hot springs and other evidences of solfatarism on its eastern margin.

LAKES OF NEGROS

In the mountains of the central part of southern Negros, west of the town of Dumaguete, are two lakes, the larger of which is called Lake Balinsasayao. These lakes lie side by side, and each is elongated in a north-south direction. Lake Balinsasayao covers an area of approximately 4 square kilometers, and the smaller lake is perhaps one half as large. Professor T. T. Crooks, of Siliman Institute, Dumaguete, has visited Lake Balinsasayao several times. He estimates its elevation at from 1,300 to 1,600 meters, and soundings taken by him reveal a maximum depth of 134 meters. The surrounding hills rise abruptly from the water's edge. The lake is well stocked with fish, and Professor Crooks recommends it as a pleasant, cool resort during the period from March to June.

LAKES OF LEYTE

There are several small lakes on Leyte Island, but there is little definite information concerning them. Lake Bito, near the eastern coast of central Leyte, is an expanded portion of Bito River. Its area is 1.2 square kilometers, and its surface is 3 meters above high tide according to the Coast and Geodetic Survey. Jagor found its greatest depth to be 13.3 meters. Adams [18] states that Lake Bito has generally been regarded as a crater lake, and while his own observations did not prove to him that the site was an old crater, he believes that the depth of the lake is greater than would be expected in the normal grade of the river.

Lake Danao is in the central portion of Leyte, 12 kilometers northeast of the town of Ormoc. Its area is the same as that of Lake Bito—1.2 square kilometers; it is at an elevation of about 500 meters and is elongated in form, lying between mountains. The outlet of Lake Danao flows into a smaller lake farther east, called Amandiuing. Lake Lunay, still smaller, is shown on older maps to the west of Lake Danao. Two small lakes lie to the south of Burauen in central Leyte. The water of one of these, Malaksan (sour), is acid and occupies part of a solfatara from which sulphur has been taken. Lake Jaruanan, the water of which is fresh, is a short distance south of, and somewhat larger than, Lake Malaksan.

Jagor states that Lake Jaruanan is 668 meters long, 330 meters wide, and 21.7 meters deep. The greatest depth is near the southern shore, which is steeper than the northern shore. Maurice Goodman visited these two lakes while examining sulphur deposits in Leyte and found Lake Malaksan to be at an elevation of 375 meters and Lake Jaruanan, which he calls Lake Pangi, at an elevation of 350 meters.

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[18] Op. cit., 340.

LAKES OF SAMAR

Samar Island is very low lying for so extended an area, but while parts of the island are said to be swampy, lakes appear to be neither very numerous nor important. The island is not well explored, however, and inland bodies of water may well have escaped notice.

Lake Calbiga is the only lake shown on most maps of Samar. It lies a little south of the central portion of the island, covers an area of about 10 square kilometers, and drains to the west through Calbiga River. The lake is said to have the form of a caldera with high, steep shores and to be of unusual scenic interest.

Three other lakes, namely, Sompotoc, Ganoy, and Sampinit, are credited to Samar by El Archipíelago Filipino, but no information is given concerning their location or size.

LAKES OF PALAWAN

A single, small lake is recorded for Palawan by Randall A. Rowley, assistant professor of geology, University of the Philippines. This lake, known to the Filipinos by the name Mañguao, lies a few kilometers inland from the town of Taytay on the east coast of northern Palawan. It is elongated in an east-west direction, is irregular in outline, and covers an area of approximately 5 square kilometers. Soundings taken at a time when the water stood 1 meter below high-water mark revealed a uniform depth of 6 meters. The lake drains to the southeast, the water escaping through the openings in a wall of vesicular or cellular basalt.

LAKES ON SMALL ISLANDS

There are a number of other small lakes distributed over the less important islands. On Pacijan Island, southwest of Leyte, there is a lake or swampy area 5 square kilometers in extent lying at, or slightly above, sea level. Its water is brackish and is probably contaminated with sea water. The small island Cagayan de Sulu contains three small lakes: Sapa, near the center of the island, with an area of 0.25 square kilometer, and Singuan and Ernestine, near the southern coast, with areas of 1 square kilometer each. The last-named lakes are circular in outline and might be supposed to occupy old craters. A third circular body of water, Jinata, has a restricted opening to the sea and is thus in reality a bay, although apparently related in origin to lakes Singuan and Ernestine. On Jolo Island are two lakes, Crater Lake and Siit Lake, each with an area of 1 square kilometer.

ILLUSTRATIONS

PLATE I

Part of Laguna de Bay, showing rice fields near the shore and the escarpment of tuff to the west.

TEXT FIGURES

FIG. 1. Map of Laguna de Bay, southwestern Luzon.
2. Map of Bombon, or Taal, Lake, southwestern Luzon.

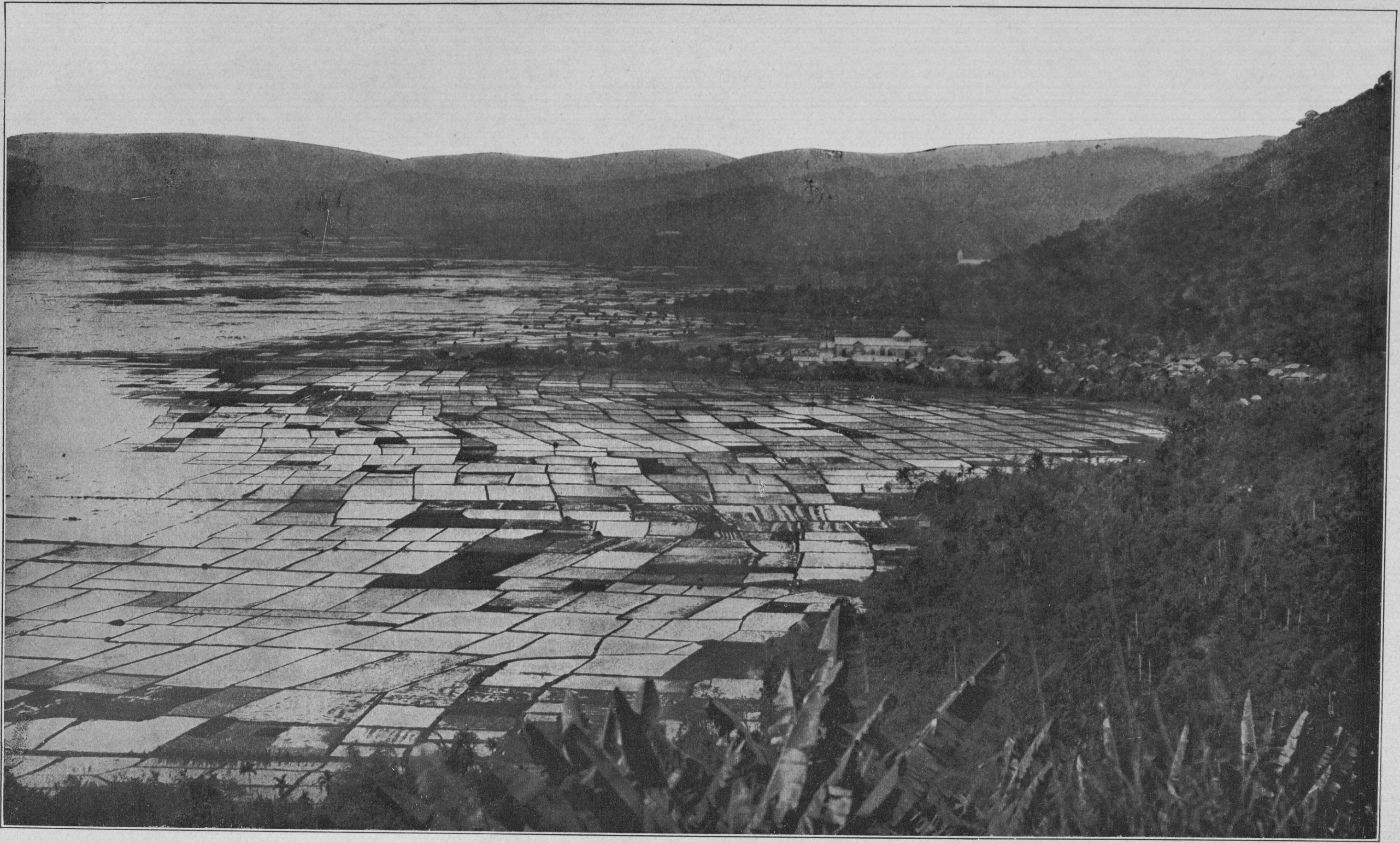

PLATE I. PART OF LAGUNA DE BAY, SHOWING RICE FIELDS NEAR THE SHORE AND THE ESCARPMENT OF TUFF TO THE WEST.

THE PALIDAN–SLIDE MINE

By V. E. LEDNICKY

(From the Division of Mines, Bureau of Science, Manila, P. I.)

In this day of scientific and economical mining a small mine is usually of little interest to the general public unless it has some unique or unusual features. The Palidan-slide mine is such a one. While actual mining in it is limited to small veins and shallow holes, it is unusual enough to be of interest to mining men or chance visitors who have the opportunity of seeing it.

In nearly all Spanish colonies are found remains of mining operations which distinctly bear the mark of the early settlers, but it is very seldom that a place is found where the Spaniards have allowed the use of old Indian methods without effecting changes. One of these places is in the mountainous regions of the Philippine Islands where the methods at present employed are known to have been used for at least five generations by the natives. The Spanish crown possessed the Islands for several hundred years, but it was not until 1850 that the first exploring expedition went into the land of the wild peoples "of a savage and ferocious character" to examine the wondrous copper deposits of the mountain region. A complete narrative of the trip has been translated by H. D. McCaskey[1] and is included in the description of the Mancayan-Suyoc region. No mention was made at that time of the gold workings by the Igorots, although gold ornaments and amulets were reported as being worn by the savages. Owing to the inaccessibility of the mines and the supposed danger from the inhabitants, the Spaniards stayed away from the northern mining district until 1865. As they were mainly interested at the time in the Mancayan copper, they ignored the gold mines, and the first reports of their entering Suyoc came some years later.

HISTORY

A brief history of the Palidan working was obtained through Mr. Charles Ambas, of Suyoc, who interrogated the natives. No definite dates were obtainable, as the Igorots divide their time vaguely into generations.

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[1] A preliminary reconnoissance of the Mancayan-Suyoc mineral region, *Bull. P. I. Min. Bur.* (1905), No. 4, 15–19.

The Suyoc Igorots have been miners for hundreds of years, and their old mine workings can be found in almost every part of the Suyoc district. There are workings all around the Palidan slide, but none is as large, although some of the veins mined before look more promising than the Palidan vein.

The Palidan vein was worked by at least four generations of Igorots before the coming of the Spaniards. It is possible that it was worked for a longer period, but the names of only four chiefs are remembered. They were Alaban, Gislang, Wasawas, and Witawit. The last, Witawit, was alive when the first Spanish military governor was put in charge of the district.

According to the history of the inhabitants, the first *comandante* attempted to take possession of the mine as soon as he saw it was valuable, but the Igorots objected. The case was finally taken to the governor-general, who ruled that owing to their long possession of the ground the Igorots were rightful owners and could not be removed. The comandante accordingly gave up his attempts to take possession and allowed the natives to work, but contrived to buy their gold at 10 pesos [2] per Mexican peso's weight (27.07 grams) of gold, a very profitable procedure which continued until the insurrection of 1895. The insurrectos took forcible possession of the property and compelled the Igorots to work throughout the season of that year. No record was kept of the gold extracted for the insurrectos, but it is probable that the amount was small.

After the American occupation the former Spanish comandante tried to obtain possession of the ground under the concession law, but his claim was disallowed. Meanwhile the Igorots continued working the ground.

In 1903, upon request of the leading Igorots, Mr. C. E. Petit staked out the ground under the American mining law for six Igorots and himself. The Igorots who signed the location notice were Congosan, Pig, Bayongosan, Madanis, Abalos, and Pagian. All of these are still working the ground with the exception of Pagian, who is now a prisoner in Hongkong.

The location of the property by the six Igorots and one American has not changed the local mining custom. The whole village still continues to regard the ground as common property and to work it as such. The real owners apparently have no more right on the ground than any other inhabitant. It thus happens that the American partner has not realized anything from the ground, but this year he has leased his share for 15 ounces (466.5 grams) of gold, paid by contribution from all the workers. This custom of common ownership is peculiar in that only those Igorots from Suyoc or their relatives who are descendants of the old miners may work in the mine. There are many cases in which men or women living in Suyoc are not allowed to work with the rest. Some of them are married into families that work, but they themselves must stay out.

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[2] One Mexican peso equaled about 40 cents United States currency. One peso Philippine currency equals 100 centavos, equals 50 cents United States currency.

The Palidan slide is situated in the southwest corner of Lepanto subprovince, latitude 16° 50′ north, longitude 120° 55′ east, about 102 kilometers north from Baguio, within 1 kilometer of the Bontoc mountain road. It is an immense cavity, washed out around the Palidan and Cadangan ravines, approximately the shape of an inverted elliptical cone whose major axis bears north 60° east. The opening is approximately 620 meters long by 430 meters wide, and the vertex, or deepest point, is very close to the central edge of the northwest quarter of the ellipse at the point where the Candagan and Palidan ravines unite. This point is about 200 meters below the average rim of the slide. The sides dip very steeply from all directions, but in general the slope from the east is more gentle than that from the south or west. This is due, of course, to the greater distance from the outlet. At places the angle of dip is 80° from the horizontal, and in no place in the solid formation is it less than 20°.

The cavity is continually being enlarged by the heavy tropical rainfall, which washes away the soft material very rapidly. The Igorots aid nature in performing this work, as they make excavations in the sides and divert channels of water in order to wash off the surface material and to expose the rich stringers of gold ore.

The geologic formation of the slide is difficult to determine exactly. The lower part is composed of the solid dioritic base, which is found underlying all of the region.[3] The diorite shows rapid weathering on exposure, but is firm enough to form steep walls for the swift-flowing streams which cut through it. The rock of the upper portion seems to be the same diorite, very badly decomposed. It is so much altered that it is impossible to make any excepting megascopic examinations. It is porous and is very highly impregnated with iron sulphides. The surface exposed to the air decomposes very rapidly and allows of excessive erosion.

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[3] *Bull. P. I. Min. Bur.* (1905), No. 4, 37.

The upper rock has been very heavily silicified in altering, and masses of a quartzose material are common. It shows a great network of little veinlets or stringers of quartz which are the results of a secondary infiltration into cracks and crevices, suggesting dehydration of a large mass rather than dynamic causes. These little veinlets of stringers are usually an indication of gold values.

Wherever the veins are wider, they present a banded structure of quartz and a bluish white kaolin known by the natives as "pitoc." A fibrous variety of gypsum, white in color and with a shiny luster, and fibers that are usually curved and transverse to the veins alternate at times with the kaolin. It is an indication of rich gold values and is very closely observed by the Igorots. Several kilograms of gold are said to have been removed from a single pocket in the gypsum.

Exposed in the slide are several rather prominent veins, which have been worked for gold by the Igorots. The most prominent of these, the Palidan and Cadangan veins, have produced the greatest amount of gold within the past few seasons. The gold occurs free in the ore in rather fine particles. The ore is very similar in color to the iron sulphide and is distinguished with difficulty by any one not well acquainted with it. The natives who have been handling the ore since childhood recognize the free gold at a glance, the rapidity with which they judge a piece of ore being almost unbelievable.

The mining season at Palidan lasts from one to six months, and from 40,000 to 80,000 pesos' worth of gold is recovered from the ground in that time. The miners start work immediately after one rainy season and continue until the next, when the ground becomes subject to slides and consequently dangerous. About two hundred men, women, and children are actively employed in the work. Of these, the majority are women, the rest are children, and a small number are men.

The method of working is that used in other countries known as "booming." In the smaller veins and in the beginning of the Palidan slide, dams have been built across gullies to form reservoirs, which are allowed to fill either with rain water or water from a small creek. As soon as the reservoir is full, the gate is opened and the flood of water is allowed to tear away the overburden from the vein. Between washings the native workmen place timbers or make such excavation as they consider necessary for more rapid cutting. The dams are usually built of sod, laid flat and reënforced with poles driven into the ground on either side.

The gate is unique and very efficient. It consists of a rough wooden frame several meters long and about half a meter wide set upright into the sod dam and luted into place with a very plastic clay. To the inside of the uprights and bottom of the frame are nailed strips, or cleats, against which the door is pressed by the force of the water.

The door itself is a thick, hewn pine board which fits loosely in the large frame. Its edges are beveled at an angle of about 60° to its face. The upper part of the door is tied to the top of the frame by a piece of bejuco to prevent its being carried away when the door is opened. To operate the reservoir, the door is placed in position with the wider face pressing against the cleats. With a pointed stick a long, water-soaked rope is forced around into the wedgelike crack left between the frame and the door. This seals the opening so effectually that scarcely a drop of water escapes. The pressure of the water tends to tighten the packing, and there is little danger of its coming out unexpectedly.

To open the gate against water pressure, the operator simply pulls out the rope packing and pries against the top of the board with a stick. The water pressure does the rest. It takes less than one minute to replace the gate after the water has run out.

In the Palidan slide the working has become so large and is so favorably situated that the rains of the wet season do most of the work necessary in washing off the overburden. As soon as the rainy season is safely over, the natives go into the slide and examine it for veins. Of late years they have worked on one vein about 2 meters wide with an enriched stringer not over 0.5 meter in width. They start in wherever this vein happens to be exposed most advantageously. In most places the vein is comparatively soft and can be worked out from the surface with hand bars. The latter are usually old drill steel obtained from Americans or mild-steel reënforcing rods which have been obtained from Chinese traders. The bit is sharpened into chisel shape about 6 millimeters wide, or else it is pointed like a gad. For greater convenience, and in order to make possible the utilization of short pieces of steel, the bar is inserted into a handle, a piece of pine with a knot on the end into which a socket for the bar is burned.

When rocks too hard for hand spuds are encountered, and when powder is not available, fire and water are used. This method is very efficient though slow. As the working is deepened, stulls are put in which achieve the double purpose of holding up the hanging wall and of serving as perches for the women ore sorters. The stulls are of pine, about 20 centimeters in diameter with regular head boards and wedges. They are furnished and put in by the men, this being the only work in which women do not seem to take a leading part.

In order to accommodate the one hundred fifty to two hundred persons, and for convenience in handling ore, the exposed vein is divided into sections which are worked by different sets of individuals. Each set has its preferred right in the section to which it is assigned and conducts mining operations to suit itself. This procedure allows for a diversity of opinions and leads to better mining. In each open stope the actual mining is done by a few men and women who wield the spuds, and who, of course, have first pick at any rich pockets of ore. They take turns at the face, so that all have an equal chance. Immediately back of the miners are the women and children. The hats the women wear serve a double purpose—as a protection against falling rocks and as ore baskets. They are made of bejuco and bamboo, with small, square bottoms and wide, flaring sides. They vary in width from 30 to 40 centimeters and are about 12 centimeters deep. The women and children catch the ore in their baskets as soon as it is broken down. They examine it once by the dim pitch-pine light, and if it is extra good, they cover it with another basket and send it to their relatives on the surface, who inspect and sort it more carefully. If it is nothing out of the ordinary, they pass it back to the woman next in line, who examines it and passes it back, this procedure being followed until it has been passed from hand to hand by the dozens of women packed in the stope.

What is left when it reaches the surface is given a final inspection and is dumped or saved.

The waste is thrown back into those parts of the stope which have been worked out and bulkheaded off from the rest of the stope, so that the actual open space is small and few accidents from caving take place. Since the ore is snatched away so rapidly, the miners are never in need of muckers, and as the appointed timbermen keep the stulls advancing with the face or bottom, the miner's task is an easy one. A white man could never work under the same conditions. The air inside is very stale, and the odors from the women packed in immediately back of the miners and the sooty smoke from the pine torches make it especially disagreeable. At times, when good ore is coming out, the women are so tightly jammed in the stope that it is necessary for the miner to walk out over their shoulders.

In case of an exceptional strike it is customary for the women to fight and pull each other's hair to get advantageous positions. Fortunately no one has ever been killed in one of these fights. The women and children are very expert in hand picking, and can tell almost at a glance whether or not the specimen is of value. They look for free gold after moistening the rock with their lips. Although hundreds of pieces are examined in this way almost every day, there seems to be no transmission of communicable diseases nor sickness resulting from swallowing so much earth.

The fine ore that is discarded and all the sulphide wash are concentrated and reconcentrated several times before they are allowed to escape to the river below. The concentration is carried on in shallow, oblong depressions in the hillside, about 1 meter long by 0.5 meter wide, into which a tiny stream of water is delivered by a small flume made of straight, grooved pine trees. The woman operator works the ore back and forth in the depression until all the gangue has been washed out, leaving only rich sulphides. She keeps the latter in a basket for further treatment at home.

The depressions which serve as concentrators are located on the hillside, one above the other, the one below taking the tailings from the one above and so on. The tailings are concentrated at least six times before they are turned into the river, so that the actual residual gold content is then very small.

The rich ore and the concentrates are taken home and there ground in a native mill, then panned in a bark pan, smelted, and finally sold. The crusher is a large, flat stone, usually of diorite, about 0.5 to 1.5 meters long, with a depression hollowed out in the center. After being broken by hammering between two stones, the ore is placed in this hollow and is crushed down so fine that it would pass a sieve having 40 meshes per centimeter (100 meshes per inch). The muller, or rubstone, weights 15 to 20 kilograms and is usually of the same hard stone as the bottom.

The ore is always well mixed with water, and the rubbing is a direct pushing and pressing such as is used in washing clothes on a washboard. The fine ore is collected in an earthen pot and is then panned.

The pan is a piece of bark about ½ to ⅔ meter long by ⅓ meter wide. About 6 centimeters of the sides are bent up and held in position by two pieces across the top near the ends. These pieces also serve as handles. The action in panning is very similar to that of the belt vanner. The native places the pan with ore on it in a small tank of water whose depth is just sufficient to cover the top of the crosspieces. By grasping a crosspiece in one hand and lifting, a current of water is caused to pass over the ore and wash off the lighter material. With the other hand the operator returns the mineral to the head of the pan and again lifts. The motions are regulated to a nicety, and the separation is very cleanly made. In order to separate the gold from the rich sulphides, a slight side shake and roll are given the bark pan. When handled by a skillful manipulator, the gold seems to travel up and away from the sulphide. The tailings are carefully saved and panned over in the rainy season when mining is impossible. Some observers have reported that the natives bury the tailings and expect the gold to come back to them. This belief is easily explained by the fact that the sulphides oxidize very rapidly after being once ground and no doubt release some gold that is coated by the iron sulphide. The fine-gold pannings are melted with a small amount of lead in a wide clay crucible somewhat similar to a scorifier. The melted product is poured and is then placed in another clay dish with a covering of salt and given a chloridizing roast. When this is done properly, the gold has a very pure appearance, although in reality it is only about 700 fine. I was unable to ascertain if this chloridizing was done with the deliberate intention of deceiving the purchaser or merely to improve the appearance of the product. Since the method of buying after comparison on a touchstone has been adopted, chloridizing has become obsolete.

The Igorots have many curious superstitions in regard to mining, and very great faith is placed in their religious offerings to the "anitos," or spirits. These religious observances take the form of *cañaos*, or feasts, at which *tapuy*, a liquor made from fermented rice, is drunk and animals are killed and eaten.

If a low-grade rock is encountered in mining, it is customary to hold a cañao to improve it. If a rich pocket is struck, a stop must be made and a cañao of thanksgiving is held. Meanwhile some Igorots, not quite so superstitious as the rest, may slip down into the mine and steal the ore, leaving just enough to keep the others somewhat appeased. Whenever a theft is discovered, some one must be punished. More cañaos are necessary, and curious trials to determine the culprit are held.

The women remain continent during the mining season, and never wash their bodies so long as the vein is producing, for fear that the gold will disappear. If it thunders, the Igorots must perform a cañao, and if any cloth is burned near the mine, they will not work until the proper anito has been appeased. They burn nothing but pitch in the workings; a lighted candle taken into the mine would create much excitement.

About 60,000 pesos in gold are produced yearly out of Palidan. Most of this, or about 45,000 pesos' worth, is sold to buyers, who use the old Spanish custom of buying by the old Mexican peso weight (28.34 grams). Ordinarily about 20 to 30 pesos are paid per peso weight of gold. By taking advantage of natives who are forced to sell in order to give cañaos, unscrupulous buyers are able to get a large fraction of the output at an even lower figure. The remainder of the gold not sold outright is made into jewelry or buried under the houses until needed.

Good miners are known to take out several hundred grams of dust in a single season. These are, of course, expected to give larger cañaos, so they remain practically as poor as the rest.

ERUPTION OF BULUSAN VOLCANO[1]

By J. P. Goldsberry

(*From the Division of Mines, Bureau of Science, Manila, P. I.*)

INTRODUCTION

The first news of the eruption of Bulusan Volcano was a telegram received January 21, 1916, by the Director of the Weather Observatory in Manila and sent by the municipal presidente of Irosin. This telegram, dated January 20, stated that Bulusan Volcano was in a state of eruption, beginning January 18 at 2 o'clock in the morning, with action continuing, accompanied by the pouring of ashes, landslides of fire, and ejection of mud and also heavy rains and strong winds.

On the day received, the Director sent a message to the presidente of that municipality requesting more detailed information in regard to seismic disturbances, the nature of the ashes, whether hot or cold and the quantity, the direction of the wind, the effect upon the vegetation close to the crater, the gases evolved, and the location of the mountain.

In answer to the requests made, the Director received on January 23 a second telegram, dated January 22, from the presidente of Irosin containing the following information:

> Cold ashes fell. Smoke issued during first forty-five minutes. Eruption continues to date, but with less ashes. Direction of ashes is southwest due to winds from the northeast. Radius of ashes from the crater is 25 to 30 kilometers. One remarkable quake occurred on the 18th at 4.00 a. m. Vegetation up to the crater is alive. The river from the volcano is heavily charged with ashes. Little fire comes out. Subterranean noises are almost continuous, but in general almost imperceptible. Thickness of ashes on the town at the close of the first day of the eruption was 0.5 centimeter. During the afternoon of January 21 there were intense waves of sulphur fumes during the first 8 hours. On January 22 from 8.00 to 9.00 a. m. great noises were heard nearly every 15 minutes. After the last noise the atmosphere about the volcano became clear and the top of the volcano was visible. The distance from the town to the crater is about 15 kilometers.

TRIP TO SORSOGON

The trip to Irosin is best made by boat to Bulan, and hence by automobile to Irosin, a distance of 21 kilometers, although there are foot trails from both Juban and Bulusan. Until recent washouts in the road, there have been four auto trucks

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[1] Received for publication March 27, 1916.

plying between Bulan and Irosin, taking in rice, fish, and other supplies, and returning with hemp and copra for Manila.

The road to Irosin follows a general northeast course, crossing first about 8 kilometers of coastal plain deposits, and then by a series of grades it winds up over the divide and down into Irosin Valley. The divide consists of a chain of andesitic and basaltic hills trending northwest-southeast and forming the western limit of what Adams and Pratt[2] have designated as the third division of the Southeastern Cordillera of Luzon.

IROSIN

Irosin, including its barrios, is said to have about 12,000 people. It is situated at the foot of Mount Bulusan and forms a semicircle around the base. Aneroid readings place its elevation at from 50 to 60 meters above sea level. Being almost surrounded by mountains, it is well protected from baguios, although during the recent rainy season (November to February) floods occurred which carried out most of the bridges and caused much damage to the roads.

Arriving in Irosin in the afternoon of the 28th, I could see no confusion, and except for a small amount of fine volcanic ash in sheltered places, there were no remnants of the eruption. As the summit of the mountain was surrounded by heavy clouds, it was not possible to tell whether or not activity had entirely ceased.

1916 ERUPTION

I obtained much of the data concerning the events of the eruption from Mr. S. B. Chestnut, district school supervisor, who was in Irosin during part of the eruption. His information was supplemented by that of two Filipino school-teachers and the municipal officers. Older residents of Irosin remember the eruptions of 1886 and 1894, but very little reliable information could be obtained.

On Tuesday, January 18, about 2 o'clock in the morning, rice planters heard a faint noise, felt a slight quake, and then noticed "smoke" issuing from the volcano which settled into the valley. Ashes began to fall. No incandescence could be seen from Irosin, but people in Mombon, a barrio about 3 kilometers northwest of Irosin, claim to have seen "fire." Most of the ashes fell shortly after the initial eruption, then a small amount fell for a period of three days. All together Irosin received about 1 centimeter and Mombon about 1.5 centimeters. An odor said to resemble "gunpowder" was detectable. Reports had come from Patag, a barrio 3.5 kilometers east of Irosin, that 0.25 meter of ash had fallen, but upon investigation the thickness of ash was located in stream eddies and had been carried down from the mountain by water and not by wind.

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[2] Adams, G. I., and Pratt, W. E., *Phil. Journ. Sci., Sec. A* (1911), 6, 455.

Wednesday, January 19, was a clear day. White clouds of steam and sulphur vapor came from the volcano, seemingly from a vent near the top. Late Tuesday night or early Wednesday morning the people claim to have felt a long-continued quake which was not violent.

No disturbance was noticed on January 20 or 21, but between 7 and 8 o'clock in the morning of January 22, loud noises were heard, followed by light and dark "smoke." A small stream of milky water, which appeared the size of an arm, could be seen pouring from the crater. These disturbances are said to have continued for a period of from three to four hours, although some claimed to have heard noises during the afternoon. After the 22d no disturbances occurred except in the minds of some, who felt earthquakes and heard noises every evening. Clouds kept the mountain hidden for the following seven days.

RECONNAISSANCE ABOUT IROSIN

The day after my arrival at Irosin (Saturday, January 29) it rained during the entire morning, but about 2 o'clock in the afternoon the weather cleared and the volcano became visible.

The mountain rises from Irosin Valley to a height of about 1,500 meters. From my viewpoint the slopes appeared symmetrical and moderately steep. The summit seemed to be truncated and serrated. Small erosion gullies could be traced down the flanks and resembled the ribs of a fan. The vegetation appeared green to the top. A small crater could be seen on the southwest side, a short distance below the top, from which rolled a small spiral of white vapor. The mist, rising in the small gullies, gave some of the people the impression that the flanks were dotted with numerous small vents. The clouds soon surrounded the mountain, obscuring the view, and more showers followed.

I had decided that the first clear day I would try to make a trip to the top of Bulusan. Sunday morning it was raining at daybreak, so I spent the day in making a trip to Mombon, a barrio about 3 kilometers to the northwest of Irosin, to see the hot springs in that vicinity, after which I returned to Irosin and hence west to the divide between Irosin Valley and the

Bulan coastal plain in order to examine and get specimens of a so-called conglomerate which is exposed on the east side of the divide. It is not a water-laid deposit but a flow breccia or a volcanic conglomerate, containing igneous pebbles and bowlders, more or less rounded, in a matrix of igneous rock. I have not studied the rock under the microscope, but macroscopically the pebbles and bowlders appear to be andesite inclosed in a matrix of scoria. The andesite being more resistant stands out in relief in the exposures of the conglomerate.

TRIP TO THE CRATER OF BULUSAN

I had planned to make an attempt to reach the top on Monday if the weather permitted. A start was made about 8 o'clock from Patag barrio. The trail up to the last house, a height of 765 meters, was good. From the last house to the cogon grass, the guide had previously brushed out a trail for Mr. Elmer, a botanist from Manila. The green vegetation stopped at 1,010 meters, and the cogon grass stopped at 1,260 meters. This cogon appeared dead, but showed no signs of sintering. On the south slope much of it was covered by sand and gravel, which had been carried down recently by water and landslides.

The crater was reached at 12.30, after four hours of almost steady climbing. The aneroid gave an altitude of 1,450 meters at the crater's rim, which is from 10 to 15 meters down on the flank; however, the atmospheric conditions were so changeable that readings were not very reliable.

On the rim of the crater is a small, irregular vent whose long dimension trends north 20° west up the slope. There are three openings: the largest, 10 by 4 meters, and two small crevices, measurable in centimeters. From all of these vents there was a steady rush of steam and sulphur dioxide (SO_2) vapor. Around the orifices there were being deposited fine crystals of sulphur. In this type of sulphur formation, which is designated as the "solfatara type," crystals of sulphur are formed from sublimation. The formation of "solfataras" was formerly thought to be due to the reaction of gases, namely, hydrogen sulphide (H_2S) and sulphur dioxide, in which water and free sulphur were formed according to the reaction

$$2H_2S+SO_2=2H_2O+3S$$

but Brun[3] has shown that this reaction cannot take place in nature.

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[3] Brun, A., *Chem. Zeitg.* (1909), No. 15, 29, quoted by Hunt, W. F., *Econ. Geol.* (1915), 10, 544.

The sulphur is probably derived from pyrite (FeS_2) contained in the igneous rock. In the loose material on the slopes which has been recently carried down by water and by landslides, there is much basalt, which is conspicuous on account of the shining crystals of pyrite which are disseminated throughout the mass. When pyrite is heated with a free access of air, it evolves sulphur dioxide and gives a residue of iron oxide (Fe_2O_3) with 2 to 3 per cent sulphur, but when heated in an incomplete supply of air or in a closed retort, it volatilizes, and upon passing into a condenser or coming in contact with a cool surface, the vapor condenses as flowers of sulphur.

When pyrite burns, a considerable amount of heat is generated which in ores containing over 35 per cent of sulphur is sufficient in the burning of pyrites in the manufacture of sulphuric acid (H_2SO_4) to maintain combustion after it is given an initial start. It is well known that the oxidation of pyrite in coal seams has generated sufficient heat to fire them. In the Panama Canal Zone, during the construction of the canal, carbonaceous shales containing pyrite were heated to the point of combustion by oxidation of pyrite, and smoke issuing from vents caused much alarm to the workmen. The heat generated by pyrite oxidation is a very plausible explanation for the local heated conditions of the rocks as exhibited by numerous hot springs and minor volcanic eruptions.

A rivulet of water, formed by condensation of water vapor, trickled from beneath a large rock resting on the rim of the crater, but disappeared in the loose sand and gravel within a few meters.

On the west rim of the crater, toward the upper end, there is an indentation in the rim about 5 meters long, which resembles a lip and has resulted by the recent pouring out of water. It is through this so-called spillway that the small stream of milky water, discernible from Irosin during the eruption, flowed from the crater.

The crater wall is made up of loose, heterogeneous material comprising volcanic ash, yellow sand, gravel, and bowlders. One large bowlder (3 meters in diameter) is balanced on the west edge of the crater awaiting future rains to wash out its infirm foundation, when it will crash down the mountain side, causing much anxiety in Irosin.

CAUSES OF THE ERUPTION

It seems very improbable that the eruption of Bulusan was the after effect of some great earth movement, because the one or possibly two shocks felt were of such small magnitude as not to be perceptible at the Gubat, Legaspi, or Manila stations. I was informed by Mr. Chestnut that there had been a small amount of steam given off for several years before the eruption, which together with the existence of numerous hot springs in that vicinity indicates conclusively that the rocks are hot. That water poured from the crater and much steam was evolved would seem to involve the fact that this rainy season was a long and exceptionally heavy one.

The explanation which appears the most plausible, and the one that takes into consideration the observed facts, is that the large amount of water from the heavy and long-continued rainy season percolated through the beds of porous strata and encountered the hot rocks, and more steam was generated than could be evolved by the old vent, with the result that an explosion took place in which the old vent was widened and volcanic ash derived from the crater walls was thrown into the air and carried a distance of about 25 kilometers by the strong southwest winds. Not having seen the crater previous to the eruption, I cannot be certain of an enlargement of the old vent, but observations substantiate the belief.

I do not believe that the ash was derived from molten lava by the explosion of inclosed gases, because one would expect to find coarser fragments of vesicular lava (bombs and lapilli) scattered on the slope.

The incandescence accompanying the eruption can very easily be explained by static electricity, the particles of ash becoming electrified by friction and discharging in the moist atmosphere.

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